SPECIFICATION

To All Whom It May Concern:

Be It Known That I, Harold I. Burrier, Jr., a citizen of the United States of America and a resident of the City of North Canton, State of Ohio, whose full post office address is 1902 Markley N.W., North Canton, Ohio 44720, have invented certain new and useful improvements in

PROCESS FOR HARDENING A CIRCUMFERENTIAL SURFACE ON A STEEL ARTICLE

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CROSS REFERENCE TO RELATED APPLICATIONS

None

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

BACKGROUND OF THE INVENTION

This invention relates in general to a process for surface hardening steel, and more particularly to a process for hardening a circumferential surface on a steel article.

Some components of machinery take the form of large steel rings that are for the most part relatively ductile and as such are easily machined and a capable of withstanding shocks, but nevertheless have critical surface areas that are hardened to withstand wear and fatigue. Typical of these components are the races of large antifriction bearings. These races, which may be several feet in diameter, must have hardened raceways to withstand the cyclic stresses of rolling elements moving over them as the rolling elements transfer loads between the races. High carbon steel lends itself to surface hardening, basically by heating the surface to be hardened into the austenitic range for the steel and then quenching. The quench converts the austenite into martensite which is extremely hard. This works well for small rings where the steel at the critical surface can be heated to a generally uniform temperature with a heat source, such as induction heating equipment, a flame, or even a high energy beam which is directed at a localized area of the critical surface while the ring is rotated - a "circumferential scan" so to speak. The temperature produced by the heat source must be high enough to transform the steel at the critical surface into austenite, so that a

layer of austenite forms on the ring during the scan. Then, before the austenite has time to transform, the ring is quenched to convert the layer of austenite into martensite, which is of course very hard.

With rings of increased in diameter, this scanning procedure becomes less practical, because elevated temperatures cannot be maintained to the desired depth over the time necessary to scan the critical surface for its full circumference. To overcome the problem, some manufacturers, while still using the circumferential scan to heat the ring along its critical surface, direct a spray at the critical surface immediately beyond the heat source to effect a rapid cooling, again along a localized area of the critical surface. However, as the scan approaches its origin on the critical surface, that is at one full revolution, some overlap will inevitably occur. As a consequence, the previously hardened area at the beginning of the scan is softened by the flow of heat from the area at the end of the scan. This softened or tempered region of the critical surface is much more likely to experience fatigue failure when subjected to cyclic stresses than is the remaining fully hardened area of the critical surface.

BRIEF SUMMARY OF THE INVENTION

A principal object of the invention is to provide a hardened surface that closes upon itself on a steel ring or other steel article, with the hardened surface extending its full circumference with a generally uniform hardness – or at least without any soft segments. The invention resides in a process including heating the entire article above the Ms temperature for the steel in it, while the article remains at that temperature, heating a small area of the surface still higher to convert the steel at that small area into

austenite and effecting a progression of that small area along the surface for the full circumference of the surface and finally transforming the austenite into martensite or bainite.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 is a perspective view, partially broken away and in section, of a large ring having a circumferential surface that is hardened in accordance with the process of the present invention;

Figure 2 is a is a graph of temperature plotted against time and reflecting the heat treatment of the process for the initial area of the circumferential surface and the final area of the circumferential surface;

Figure 3 is a schematic sectional view in elevation of a heating apparatus for practicing the process of the present invention; and

Figure 4 is a sectional view of the heating apparatus taken along line 4-4 of Fig. 3.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION OF INVENTION

A large ring 2 (Fig. 1), which is formed from high carbon steel, has a critical surface 4 along which it is hardened to resist wear and withstand cyclic loads. The surface 4 lies along a thin hardened layer 6 that fades into a softer and more ductile core 8 which is more easily machined and can better withstand impacts. The hardened

surface 4 may form the entire surface area of the ring 2, but more likely, it forms only a portion of the surface area. As such, it may face inwardly toward the center of the ring 2 or outwardly away from the center or even axially. The surface 4 extends the full circumference of the ring 2 without interruption, and has generally uniform hardness on the order of 58Rc. It contains no softened or tempered regions. Actually, the surface 4 need not be on a ring, but may be on some other article where it is curved and closes upon itself. Typical of such articles are cams, tubes, and shafts, to name a few.

The high carbon steel of the ring 2 should contain between 0.50% and 1.20% carbon by weight and should further possess alloying elements that delay transformation from austenite to bainite or pearlite so as to accommodate a delayed quench that converts austenite to martensite in the process. The duration of the delay depends on the time it takes to conclude the second step of a multi-step heat treatment to which the ring 2 is subjected as part of the process. Suitable steels include AISI 52100, ASTM-A485-3, AISI A-2, and TBA-2, as well as some stainless steels.

Basically, the heat treatment includes two heating steps in addition to the quench. In the first heating step, the entire ring 2 is heated to a temperature above the martensite start temperature (Ms temperature) for the steel, which temperature is on the order of 420° F, and is maintained at at least that temperature during the second heating step. Actually, the temperature to which ring 2 is raised during the first step does not exceed the lower critical temperature at which austenite begins to form and is typically about 50° F to 100° F above the Ms temperature. Since the Ms temperature is relatively low, the first step may proceed in a heated chamber such as a gas-fired or electric furnace.

In the second heating step the temperature of the ring 2 along its critical surface 4 is elevated still higher to above the lower critical temperature for the steel, that is above the temperature at which the steel begins to transform into austenite and preferably to slightly above the upper critical temperature for the steel, but not so high as to liquefy the steel or render it mushy. For high carbon steel the lower critical temperature is between 1300°F and 1400°F and the upper critical temperature typically exceeds 1400° F to 1600° F, so the second step requires the intense application of heat without excessive penetration of the heat. This is achieved by subjecting only a very localized area of the critical surface 4 to a focused heat source that is capable of directing enough heat on the localized area to raise the temperature at the localized area of the critical surface 4 - and the steel immediately below it - to above the lower critical temperature, thus creating an austenitic layer at and immediately beneath the surface 4. However, the steel in the core 8 beneath the austenitic layer, having never reached even the lower critical temperature, retains its original microstructure. The focused heating progresses along the critical surface 4 for the full circumference of the critical surface 4 and can be characterized as a circumferential scan. Once the focused heat source passes beyond an area of the critical surface 4, that area cools somewhat rapidly back to the temperature at which the ring 2 is maintained, that is the temperature established in the first heating step. However, the austenitic microstructure remains in the thin layer beneath the surface 4, since the entire ring 2 exists above the Ms temperature. No further transformation occurs within a reasonable time afterwards.

After a steel is transformed into austenite and held slightly above the Ms temperature, it will not remain austenite forever, but with time will transform into bainite.

Thus, if the layer 6 is to contain martensite, the time to complete the scan should not exceed the time that it takes the steel to begin the transformation from austenite into bainite at the temperature at which the ring 2 is maintained. Were it otherwise, the steel along the critical surface 4 initially exposed to the heat source would become a bainite, which is also hard, but not as hard as martensite.

The focused heat source used to effect the second heating step may take the form of an induction coil, a flame head, or a generator of a laser or other high energy beam. It is focused in the sense that it heats only a small area of the critical surface 4, not a long circumferential extent of the surface 4.

Once the focused heat source has progressed over the entire critical surface 4 for the full circumference of that surface 4, the entire ring 2 is immediately quenched by immersing it in a liquid or subjecting it to circulating air, with the quench being sufficient to lower the temperature along the critical surface 4 beneath the Ms temperature. The quench converts at least some of the austenite into martensite, and transforms the austenitic layer into the hardened layer 6.

The process may be represented by a plot (Fig. 2) of temperature against time for the initial focused heating I along the critical surface 6 and the final focused heating F which occurs at nearly the same location along the critical surface 4. As a consequence of the first heating step, the ring 2 throughout exists at a temperature Tr which is above the Ms temperature, but below the lower critical temperature. The heating of the initial area I of the surface 4 during the second heating step is reflected by a rapid rise in temperature from the ring temperature Tr to an elevated temperature Te that is at least above the lower critical temperature for the steel, then a retention of

the elevated temperature Te for a short duration, and then a decrease in temperature as the focused heat moves beyond the initial area I. The temperature of the initial area I decays to the ring temperature Tr at which it remains while the focused heating progresses along the critical surface 4. The final area F that is subjected to the focused heating – and all intervening areas as well – experiences a similar rise from the ring temperature Tr, a short duration at the elevated temperature Te, and also a similar decay, but afterwards does not remain at the ring temperature Tr as long. Generally speaking, the time between the initial rise above the lower critical temperature and the quench should not exceed the time for the steel to transform into bainite at the ring temperature Tr. In any event, all areas of the critical surface 4 undergo the quench simultaneously, and it is reflected by a further, somewhat precipitous, drop in the temperature from the ring temperature Tr to the Ms temperature and below.

As the layer of austenite along the critical surface 4 drops below the Ms temperature it begins to transform into martensite and create the hardened layer 6. Preferably the temperature at which the transformation to martensite is essentially complete (Mf temperature) is above the temperature of the quenching medium, so that essentially all of the austenite transforms into martensite.

Thus, that much of the ring 2 that formerly existed as austenite, that is the austenitic layer, after the quench exists as martensite, and that portion is along the critical surface 4 and the layer 6 immediately below it. Hence, the critical surface 4 and the layer 6 possess a hardness greater than the core 8, and the hardness is uniform along the entire surface 4, there being no softer tempered zone in it. Some tempering may be required to reduce the hardness and impart a measure of ductility to the steel

along the surface 4 and in the layer 6, and this tempering may be achieved by terminating the quench while enough heat remains in the core 8 to soak back into the hardened layer 6 and temper the steel in it – in effect, a self-tempering. On the other hand, the tempering may be achieved by reheating the ring 2.

The uniform cooling during the quench reduces dimensional distortion to a minimum. Moreover, the martensite, which is formed during the quench, attempts to expand relative to the core 8, so the steel in the layer 6 at the critical surface 4 exists in a state of compression, which is desirable for many applications, particularly where the critical surface sees cyclic stresses, as does the raceway of an annular bearing race.

A heating apparatus 10 (Figs. 3 and 4) in which the two heating steps of the heat treatment proceed, includes a carriage 12 having a pedestal 14 that supports a table 16, with a thrust bearing 18 being interposed between the table 16 and the pedestal 14, so that the table 16 can rotate about a vertical axis on the pedestal 14. The carriage 12 also includes a motor 20 for rotating table 16 about the vertical axis. The table 16, which is circular, carries several support blocks 22 which are formed from a substance having low thermal conductivity and are arranged in a circle about the vertical axis to create a cradle which receives the ring 2 and supports it above the upper surface of the table 16.

The heating apparatus 10 also includes a furnace 26 having a circular side wall 28 and a top wall 30 attached to the upper end of the side wall 28 to close the top of the furnace 26. The circular side 8 wall is large enough to fit around the table 16, although with relatively little clearance between the circular periphery of the table 16 and the inside surface of the side wall 28. Where the furnace 26 is so fitted to the table 16, the

table 16 closes the bottom of the furnace 26. In effect, the side wall 66 and the wall 30 of the furnace 26 together with the table 16 enclose a chamber 32. The side wall 2 and top wall 30 are lined with blanket insulation, and along the side wall 28 the furnace 26 is further provided with resistance-type electrical heating elements 34 for elevating the temperature of the chamber 32 – indeed, to the ring temperature Tr of the first heating step. The furnace 26 is suspended from cables 36 which enable it to be moved along vertical guides 38 between an elevated open position and a lowered operating position.

When the furnace 26 is in its elevated open position, enough clearance exists between the bottom of the furnace 26 and the table 16 to enable the carriage 12, with the ring 2 supported on the support blocks 22 over the table 16, to be moved beneath the table 16. When in the lower operating position, the furnace 26, together with table 16, encloses the chamber 32.

Finally, the heating apparatus 10 includes a focused heat source 40 which is presented opposite a small region of the critical surface 4 of the ring 2. It may contain a coil suitable for effecting an induction heating of the ring 2 at the small area of the critical surface 4 toward which the heat source 40 is presented, a flame head for discharging a flame that impinges on the critical surface 4 at the small area, a generator of a laser or other high energy beam that is directed at the small area, or a plasma generator directed at the area, among other focused heating devises. Irrespective of its mode of operation, the focused heat source 40 has the capacity to elevate the temperature of the small area of the critical surface 4 toward which it is presented – and the steel immediately behind that area as well – to at least above the lower critical temperature for the steel and preferably above the upper critical temperature.

In the operation of the heating apparatus 10, the ring 2, while the furnace 26 is in its elevated open position and the carriage 12 is displaced from the furnace 26, is lowered onto the support blocks 22 on the table 16, so that the blocks 22 cradle the ring 2 and position the ring 2 such that its center coincides with the axis of rotation for the table 16. The carriage 12 is then moved to position its table 16 and the ring 2 on it beneath the open bottom of the furnace 26. Moveover, the focused heat source 40 is adjusted such that when the furnace 2 is lowered to its operating position, the heat source 40 will be presented opposite the critical surface 4 on the ring 2.

The furnace 26 is lowered into its operating position, and the heating coils 34 are energized. The temperature within the chamber 32 rises and so does the temperature of the ring 2. When the temperature of the ring 2 stabilizes at a ring temperature Tr exceeding the Ms temperature for the steel by about 50° F to 100° F, the motor 20 for the table 16 is energized and the table 16 begins to rotate, although quite slowly, moving the critical surface 4 of the ring 2 past the focused heat source 40. After the table 16 begins to rotate, the focused heat source 40 is energized. The angular velocity of the table 16 and the heat generated by the heat source 40 are such that the temperature of the ring 2 at the limited area of the critical surface 4 toward which the heat source 40 is presented rises at least above the lower critical temperature to a temperature Te and remains at that temperature Te long enough to adequately autenitize the steel at the limited area before dropping below the lower critical temperature.

When the table 16 has completed one revolution, the furnace 26 is raised to its elevated open position and the ring 2 is quenched, such as by subjecting it to a stream

of cool air while it remains on the table 16 or by lifting it from the table and immersing it in a liquid.

In extremely large rings 2 several focused heat sources 40 may be installed in the furnace 26 at equal circumferential intervals. In this way the table 16 need only rotate through the angle between successive heat sources 40 to heat the critical surface 4 for its full circumference, and this of course reduces the delay between the heating of the initial area and the heating of the final area and may be necessary to keep the duration of that delay below the time in which bainite begins to form.

Bainite is not altogether undesirable in that it too is hard. In lieu of quenching the ring 2 to convert the austenitic layer along the surface 4 into martensite after the scan is complete for the full circumference of the critical surface, the ring 2 may be maintained at the ring temperature Tr, which is above the Ms temperature, long enough for the austenite in the austenitic layer to transform into bainite for the full extent of the critical surface 4. The ring 2 is then allowed to cool to the ambient temperature at any convenient rate. The result is a hardened layer 6 of bainite instead of martensite.

The process has utility in connection with steel articles other than large rings and other than bearing races. Indeed, it may serve to provide a hard circumferentially extending surface on other articles made of steel. For example, it may be used to provide a hardened surface on a shaft, or on a tube, or on a cam, or for that matter on any article which has a curved surface which closes upon itself. In that context, the word "circumferential" has meaning beyond purely circular surfaces.